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NAVAL ENGINEERING EXPERIMENT STATION ANNAPOLIS MD
ENDURANCE TEST OF PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE--ETC(U)
MAR 50 A R SCHRADER

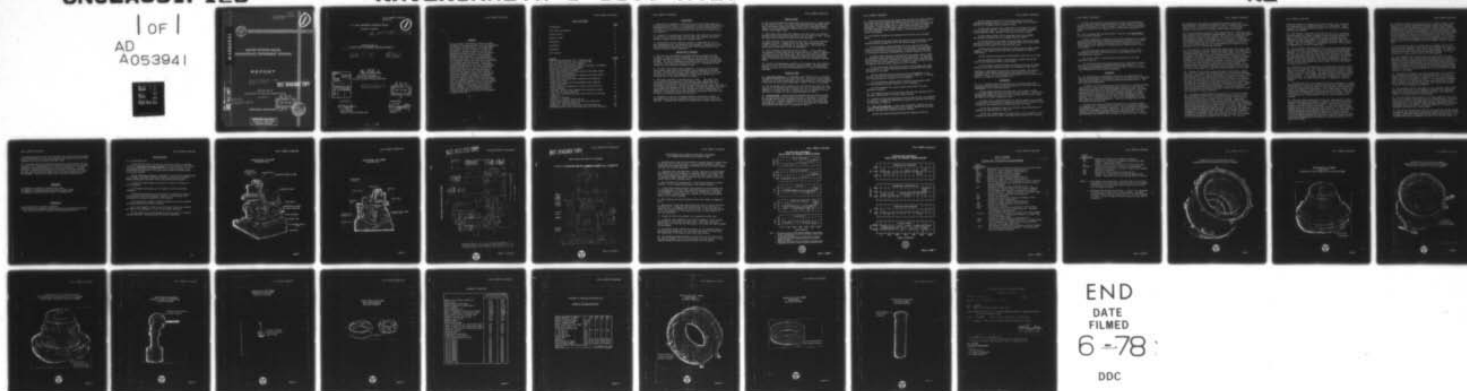
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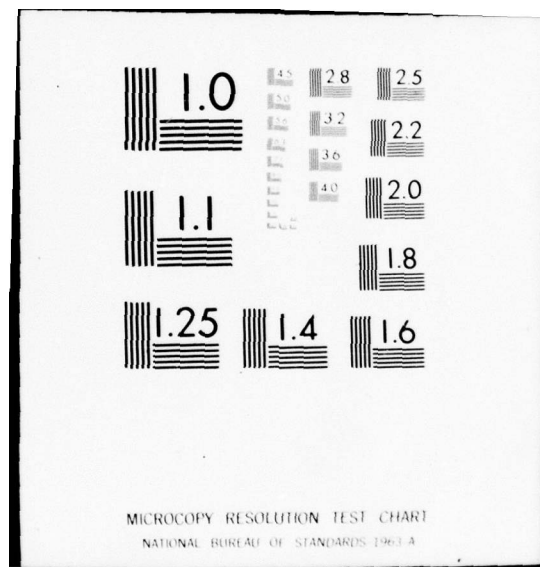
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E.E.S. REPORT C-3599-A(2)
30 MARCH 1950

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UNITED STATES NAVAL
ENGINEERING EXPERIMENT STATION

REPORT

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ENDURANCE TEST OF
PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE

- NS-623-071 -

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U. S. NAVAL ENGINEERING EXPERIMENT STATION

Annapolis, Maryland



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PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE

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By
Alan R. Schrader
14 Alan R. /Schrader
Small Diesel Engine Branch
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ABSTRACT

A Philips Model 1/4D external combustion engine, equipped as a portable generator set, was operated as continuously as practicable at its rated output, 124.5 watts, or more, in order to indicate its reliability. The performance of the unit was generally satisfactory except for the following: fouling of the fuel nozzle on five occasions; excessive carbon deposits in the gasoline-air mixture venturi tube on one occasion; failure of the compressor suction valve seat disc; and failure of the heater head thermocouple. The engine operated satisfactorily with Amoco water white (lead free) gasoline for 500 hours and leaded 80 octane motor fuel for 30 hours. The test was discontinued after 597 hours operation due to failure of the engine's main roller bearing. A post-trial disassembly inspection of the engine showed that it was in generally satisfactory condition except for the failed roller bearing, slight to moderate fouling of the internal cooler fins and somewhat excessive wear of the compressor piston tappet face and of the piston pins, displacer crankpin, and displacer rod and their mating bushings. It was recommended that the engine be tentatively considered suitable for limited service use and that certain improvements be made in the unit.

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INTRODUCTION

1. Reference (a) reported the results of test of two Philips Model 1/4D external combustion engines. The performance of these engines was generally unsatisfactory due to the many casualties and operating difficulties encountered. The major deficiencies were found to be in the attached auxiliary equipment.
2. A third unit incorporating numerous design modifications was delivered to this Station 3 October 1949. Test of this unit, reported herein, was started 4 October and was completed 5 December 1949.
3. Authorization for this test is contained in references (b) and (c). Cost classification "W" and NS-623-071 were assigned. The priority of the test for November 1949 was A-2 in the Small Diesel Engine Branch of the Internal Combustion Engine Laboratory.

DESCRIPTION OF MATERIAL

4. The unit was constructed as a portable electric generator set and comprised the engine, electric generator, air and fuel tanks, and other necessary auxiliary equipment. All components were mounted on a skid-type sub-base. The electric generator was direct-connected to the engine shaft; its normal output was 124.5 watts at 130 volts d-c. Photographs of the complete unit are presented on Plates 1 and 2.
5. The engine was rated 1/4 bhp at 2500 rpm. It was a single-cylinder model having a power piston and displacer piston operating in the same cylinder. The cylinder bore was 2-1/2 inches and the strokes of the power and displacer pistons were respectively 1-7/32 inches and 3/4 inch. A sectional view of the engine is shown on Plate 3.
6. The engine operated on the Stirling air cycle. Basically, this cycle consisted of compression of the working charge taking place at a relatively low temperature, followed by an addition of heat, then high temperature expansion and, finally, cooling of the working charge. Functioning of the engine was dependent on the fact that more power was derived from the high temperature expansion than was required for the low temperature compression. Air was used as the working charge, the same air being used over and over by alternately heating and cooling it.
7. Combustion of the fuel took place entirely outside the cylinder. A grate-type burner and an air pressure atomizing type of fuel nozzle were employed. The engine was cooled by air supplied by a flywheel-mounted fan.

METHOD OF TEST

8. The unit was operated as continuously as practicable at a power output of 124.5 watts or more. The heater head temperature was maintained at a level sufficient to permit that power output, with a reasonable reserve margin, to obviate excessively frequent adjustment of the gasoline flow control manual needle valve.

9. Amoco water white (lead free) gasoline was used during all operation reported herein, except during the 500 to 530 hour period of test. During the latter period, leaded 80 octane motor fuel was used.

10. Shell Albis No. 29 lubricating oil was used in the engine crankcase throughout the test. Changes of the oil were made at approximately 50-hour intervals, as recommended by the contractor. Navy Symbol 9370 lubricating oil was used for the air compressor.

11. Fuel consumption measurements were by weight. A float valve was used between the weigh tank and the engine fuel tank in order to maintain a constant level in the engine tank. The fuel flow between the engine tank and the burner fuel nozzle was by the normal path provided by the engine construction and was not affected by the fuel consumption measurements.

12. A post-trial disassembly inspection of the engine was made following completion of the 597 hours operation reported herein. All parts were examined visually and micrometer measurements of the major wearing parts were made.

RESULTS OF TEST

13. Pre-trial Inspection - In compliance with reference (b), no pre-trial disassembly inspection of the engine was made. An external visual inspection of the unit, and conversations with a representative of the contractor, showed that the modifications described on Plate 4 had been incorporated.

14. The dry weight of the complete unit, as received, was 135.3 lbs. The capacity of the crankcase was 0.1 gallon (3/4 lb) of lubricating oil. The capacity of the fuel tank was 0.5 gallon (3.2 lbs) of gasoline; this was sufficient to operate the unit for approximately five hours.

15. Endurance Test - Engine operation was generally satisfactory except for the casualties and difficulties described in paragraph 17 following. The average specific fuel consumption during the 597 hours of test was 4.30 lb/kw-hr. A graphic presentation of the pertinent performance and operating data is given on Plate 5. A log of test operation indicating all shutdowns and casualties is presented on Plate 6.

16. Inspection of the burner and heater heads following 500 hours operation with Amoco water white (lead free) gasoline showed them to be free of appreciable deposits, Plates 7 and 8. Cleaning of the parts was considered unnecessary. A second inspection of these surfaces following 30 hours subsequent operation with 80 octane leaded motor fuel again showed them to be satisfactorily clean, Plates 9 and 10; cleaning was again considered unnecessary.

17. The observed casualties and operating difficulties are summarized below:

(a) Cleaning of the fuel nozzle was required on five occasions, after operating periods ranging from 13 to 181 hours (average, 105 hours).

(b) The synthetic rubber diaphragm of the air shut off valve was found to be perforated and stuck to its seat after 209.5 hours operation, preventing the engine from being started. A replacement diaphragm made by this Station functioned satisfactorily during the balance of the test.

(c) Heavy carbon deposits in the gasoline-air mixture venturi, Plate 11, prevented proper combustion after 250 hours operation. The deposits were removed by scraping. Similar but considerably lighter deposits were removed after 431 hours operation of the engine; it was uncertain whether the deposits affected engine operation on this occasion.

(d) The heater head thermocouple failed by wire breakage after 329 hours operation. A spare thermocouple already installed was used during the balance of the test.

(e) The compressor suction valve failed by disintegration of the silicone rubber seat disc after 430 hours operation, Plate 12. A replacement head assembly was installed on the compressor.

(f) The compressor mounting bolts loosened on one occasion, after 512 hours operation, causing vibration of the compressor.

(g) The crankshaft main roller bearing failed after 597 hours operation, Plate 13.

18. The endurance test was discontinued after 597 hours operation due to the above-noted failure of the main roller bearing.

19. Analyses of the gasolines used as fuels during the test are presented on Plate 14. Analyses of representative samples of crankcase lubricating oil are shown on Plate 15.

20. Post-trial Inspection - A post-trial disassembly inspection of the engine, after 597 hours operation at this Station, showed that all parts were in a satisfactory condition except as follows:

(a) The main roller bearing had failed by spalling, Plate 13.

(b) The internal fins of the cooler were coated with an oily carbonaceous deposit, Plate 16. It is estimated that the flow restriction due to the deposit was 10 percent or less.

(c) The lower quarter of the regenerator was blackened by carbon and oil deposits, Plate 17. The balance of the regenerator appeared to be relatively clean, although it was dulled and heat-colored.

(d) The tappet surface of the compressor piston was indented and pitted from contact with the crankpin bearing, Plate 18.

(e) The butt gaps of the first and second piston compression rings and the oil control ring were 0.007, 0.008 and 0.018 inch, respectively. The specified butt gap of all rings was 0.004 inch.

(f) The maximum clearance between the piston pins and their mating bushings in the connecting rod was 0.003 inch (specified 0.0006 to 0.0007 inch).

(g) The connecting rod was bent approximately 1/16 inch out of true.

(h) The maximum clearance in the displacer crankpin bearing was 0.0021 inch (specified 0.0008 to 0.0010 inch).

(i) The maximum clearance between the displacer rod and its mating bushing in the lower piston was 0.0015 inch (specified 0.0004 inch).

According to measurement data supplied by the contractor, the initial clearances of the several engine parts noted above were within the specified ranges. Pre-trial micrometer measurements were not made by this Station, in compliance with reference (b).

CONCLUSIONS

21. It is concluded that the performance of the Philips Model 1/4D external combustion engine during the endurance test reported herein was satisfactory in the following respects:

(a) The engine developed its rated power, 124.5 watts, or more, during substantially the entire 597 hours of test operation. Power output was generally deficient only during brief periods when the burner nozzle was found to be fouled following a start.

(b) There was no observed tendency for harmful deposits to be formed on the heater or burner head surfaces during the 597 hours operation, which included 30 hours operation with leaded 80 octane motor fuel.

(c) The fuel consumption rate, 4.30 lb/kw-hr, was satisfactory considering the type and size of this unit.

(d) The unit started easily by means of the rope-pull starter on all occasions as soon as the heater head temperature reached 950°F or higher.

(e) The lubricating oil change periods, 50 hours, were satisfactory for this type unit, particularly considering the small quantity of lubricating oil involved, viz., only 0.1 gallon. Analyses of the used lubricating oil indicated that the change periods could be safely extended to 75 hours.

22. It is concluded that the performance of the unit was unsatisfactory in the following respects:

(a) The reliability of operation was not fully adequate due to fouling difficulties with the burner nozzle and gasoline-air mixture venturi tube. Cleaning of the fuel nozzle was required on five occasions, and heavy carbon deposits were observed in the gasoline-air mixture venturi tube on one occasion.

(b) The compressor suction valve seat, of silicone rubber, had an inadequate service life; this part failed by disintegration after 430 hours operation, Plate 12.

(c) The main roller bearing failed by spalling after 597 hours operation, Plate 13.

(d) The heater head thermocouple design was not sufficiently rugged. Failure of the thermocouple occurred after 329 hours operation. Of three spare thermocouples mounted in the heater head, only one was usable as a replacement for the failed thermocouple.

DISCUSSION

23. The modifications incorporated in this unit, as compared with the previous engines tested at this Station, were chiefly concerned with simplification and improvement of the attached auxiliary equipment, Plate 4. The most important changes were:

(a) Control of the burner gasoline flow by means of a manually-operated needle valve in lieu of the complicated and relatively delicate thermostatically-controlled pilot valve arrangement previously used. The manual control was found to be quite satisfactory during the Station's tests. Adjustments were made at one to 94 hour intervals (average, 23 hours) in order to maintain reasonably uniform heater head temperatures for test purposes. It is considered that, for service use, adjustment would have been necessary much more infrequently. The means of adjustment provided were simple and quick-acting.

(b) Use of air from the flywheel-mounted fan as a secondary source of combustion air. Previously all combustion air was supplied by means of high pressure air jets used with aspirators. This modification considerably reduced the consumption of high pressure air and thereby caused the compressor to have a correspondingly increased reserve capacity. The unit was therefore less sensitive to the effects of slight air leaks. However,

the modification did result in a greatly increased starting time. Approximately ten minutes were required to raise the heater head temperature from 80°F to the 950°F required for starting. In the earlier engines, a warm up time of only about three minutes was required.

24. In all instances, starting of this engine was easy. After the heater head temperature had reached the required 950°F, the unit invariably started with one pull of the rope pull starter. The crankcase air pressure for starting was generally in the range of 70 to 80 psi. This caused the force required to pull the starting rope to be increased, as compared with the earlier engines that used only 30 to 50 psi starting pressure; however, the starting rope pull was not considered to be excessive and no particular skill or strength was required.

25. The capacity of the air storage tank, approximately 275 cubic inches, was barely adequate to permit starting the engine cold. The normal air storage pressure was 140 psi. During the warm up period prior to starting the engine, the combustion air and crankcase pressurization air were supplied by this tank. If for any reason the warm up period was slightly extended, or if initial pressure in the air tank was slightly low, replenishment of the air supply was necessary. No means of replenishing the air supply were provided in this unit, although a removable and somewhat crude hand pump was supplied with the earlier engines. It is considered that a permanently attached, easily operated manual air pump would be very desirable as a means of insuring startability of the unit.

26. Lighting of the burner was generally easily accomplished, using a flint and steel igniter that projected sparks into the combustion space. Lighting by means of a match or open flame, was not done as easily. After approximately 425 hours operation had accrued, lighting of the burner when cold was sometimes very difficult, and other times relatively easy. The cause of this condition was not determined, but it is considered possible that the gasoline may have been contaminated with water. During the difficult starting period, the gasoline used was taken from a near-empty drum stored outside of the building. During later operation, gasoline was taken from another drum and the difficulty appeared to have been partially or wholly corrected.

27. In general, the performance and reliability of this unit was very much improved as compared with the engines previously tested at this Station, reference (a). The only chronic difficulty was the fouling of the fuel nozzle which occurred on five occasions. Invariably, when the fouling occurred, it was observed immediately after starting. Its effects were to reduce the gasoline flow and thereby cause inadequate heater head temperatures, which then resulted in a power output deficiency with the maximum power being limited to 100 to 120 watts. When the fouled nozzle was inspected after operation on Amoco lead-free gasoline, no reason for its malfunctioning was found. The internal surfaces and passages were invariably clean. The outer surface of the nozzle nut was usually covered with a heavy black lacquer, although in no instance did the lacquer appear to restrict the jet opening. The cleaning

operation consisted of scraping off the black lacquer from the nozzle nut, disassembling the nozzle and blowing out the passages. Proper operation of the nozzle usually resulted; if it did not, the cleaning operation was repeated.

28. Forty percent of the fuel nozzle fouling (two of five occasions) occurred during the 30 hours of operation with 80 octane, leaded motor fuel. On each of these two occasions, a black sludgy deposit that appeared to restrict the inner air jet passage was found inside the nozzle when it was disassembled. The deposit was easily wiped off with a cloth. From the foregoing, it is considered that fuel nozzle fouling was aggravated by the use of leaded fuel.

29. In no instance did fouling of the fuel nozzle cause an interruption in a continuous run. When observed, it occurred only immediately after starting. It is believed that the fouling resulted from heat flowing into the fuel nozzle from the burner head after the engine was secured. The heat apparently caused fuel vapor lock or lacquering or carbonization of gasoline or lubricating oil in the internal passages of the fuel nozzle. During normal operation, air flow over the nozzle surface and air and gasoline flow through the nozzle tended to cool it and prevent the fouling difficulty.

30. The build-up of carbon deposits in the gasoline-air mixture venturi tube, Plate 11, appears to be an inherent fault of the combustion system used on this engine. The tube is hot during operation, because of heat conduction from the burner head. Its inner surface is wetted by a coarse spray of gasoline. This creates a favorable condition for carbonization of the gasoline. It is necessary that the tube operate at a high temperature in order to gasify the fuel before it reaches the combustion chamber.

31. The above-described carbon deposits definitely interfered with proper engine operation on only one occasion, after 250 hours operation, although the deposits were cleaned out after 431 hours operation during attempts to correct low heater head temperatures. In the latter case, however, the difficulties appeared to have been caused by nozzle fouling. The carbon deposits are not regarded as a serious problem in this engine. Removal of the deposits is a simple operation and very little disassembly is required.

32. The heater head thermocouples of this unit were regarded as being unnecessarily fragile and subject to damage by vibration or by personnel contact. The thermocouples are an important control element and it is essential that they function continuously. Without the thermocouples, overheating of the heater head may occur leading to its failure; underheating, resulting in loss of power, may also occur. It is believed that the thermocouples should be made of heavier wire (present wire size, 0.006 inch) and that they should be protected in suitable conduits. It is also considered desirable that the thermocouples be readily removable; the existing thermocouples are embedded in a small hole drilled in the heater head surface.

33. Compressor valves are considered to be a difficult problem in this engine due to the small permissible clearance volume, high operating pressure, high speed of operation, and small delivery volume. However, replacement of the valves by installation of a spare head assembly is a simple operation that can be accomplished in approximately twenty minutes. For this reason, failure of the compressor suction valve seat disc after 430 hours operation, Plate 12, is not regarded as being very serious. While a longer service life for this part is desirable, it is considered that the 430 hour life observed is not unreasonable as related to the service life of the other engine parts in the present stage of development.

34. A lead wire was used for sealing the joint between the head and cylinder of the compressor. This was not very satisfactory as the two parts are turned relative to each other during assembly. The lead wire thus tended to tear or be moved from its proper location. It is considered that a copper gasket would be much more reliable.

35. The crankshaft main roller bearing that failed after 597 hours operation, Plate 13, was installed new immediately prior to shipment of the engine to this Station, according to information supplied by Mr. R. L. Adams of the Philips Laboratories. He further advised that while considerable difficulty with this bearing had been experienced during the earlier development work on the engine, the trouble had apparently been corrected by use of a narrower bearing and by the elimination of needle bearings in the engine.

36. Fouling of the internal fins of the cooler, Plate 16, at the post-trial disassembly, appeared to be moderately serious. This was the apparent cause of the increase in temperature of the cooler during the latter part of the endurance run, Plate 5. It is pointed out, however, that in spite of this fouling and the main bearing failure, the engine still developed more than its rated power, 124.5 watts, when secured at the end of the endurance run, Plate 5.

37. The excessive wear and indentation of the compressor piston tappet face, Plate 18, was due to the inadequate hardness of that surface. According to the contractor's drawing of this part, cold rolled steel without any hardening procedure was specified.

38. The most serious wear problem in this engine appeared to be in the piston pins and their mating bushings in the connecting rod. One piston pin was worn more than the other, possibly due to the slightly bent connecting rod. It is understood that increased clearance of the piston pins causes poorer oil control, leading to fouling of the cooler and regenerator and resulting in loss of power.

39. The initial over-all noise level in this engine was very low and was considerably less than that of the earlier engines, reference (a). While no exact, quantitative measurements of the noise level were made, it is considered that the unit produced less noise than a sewing machine. It

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is probable that much of the noise reduction, as compared with the earlier units, resulted from the use of a synthetic rubber flat belt to drive the compressor in lieu of the previously used chain.

40. A gradual increase in operating noise level occurred during the test operation. This was probably due to increased clearances in the operating parts and to the gradual failure of the main roller bearing. A sharp increase in operating noise occurred in the last eight hours operation; and when the test was discontinued, after 597 hours operation, the noise was excessive. This was, of course, due to the main bearing failure.

REFERENCES

- (a) EES Report C-3599-A(1) dated 25 March 1949.
- (b) BuShips ltr NObs-34195 (643-330) dated 24 August 1949.
- (c) BuShips ltr NObs-34195(643c) dated 14 November 1949.

DISTRIBUTION

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Office of Chief of Engineers, Engineer Research and Development Division,
Room 2029, Building T-7, Gravelly Point, Washington-25, D. C.

RECOMMENDATIONS

It is recommended that:

(a) The Philips Model 1/4D external combustion engine, as reported herein, be tentatively considered suitable for limited service use wherein its special features, such as quietness are of major importance and in which operating intervals of 500 hours maximum between overhauls would not be objectionable.

(b) The thermocouple design be improved by the following modifications: use of larger wire size; protection of wires by enclosure in conduit; making thermocouples removable rather than permanently installed.

(c) The fuel nozzle design be improved to reduce its tendency to foul in service.

(d) Crankcase lubricating oil be changed at 75-hour operating intervals.

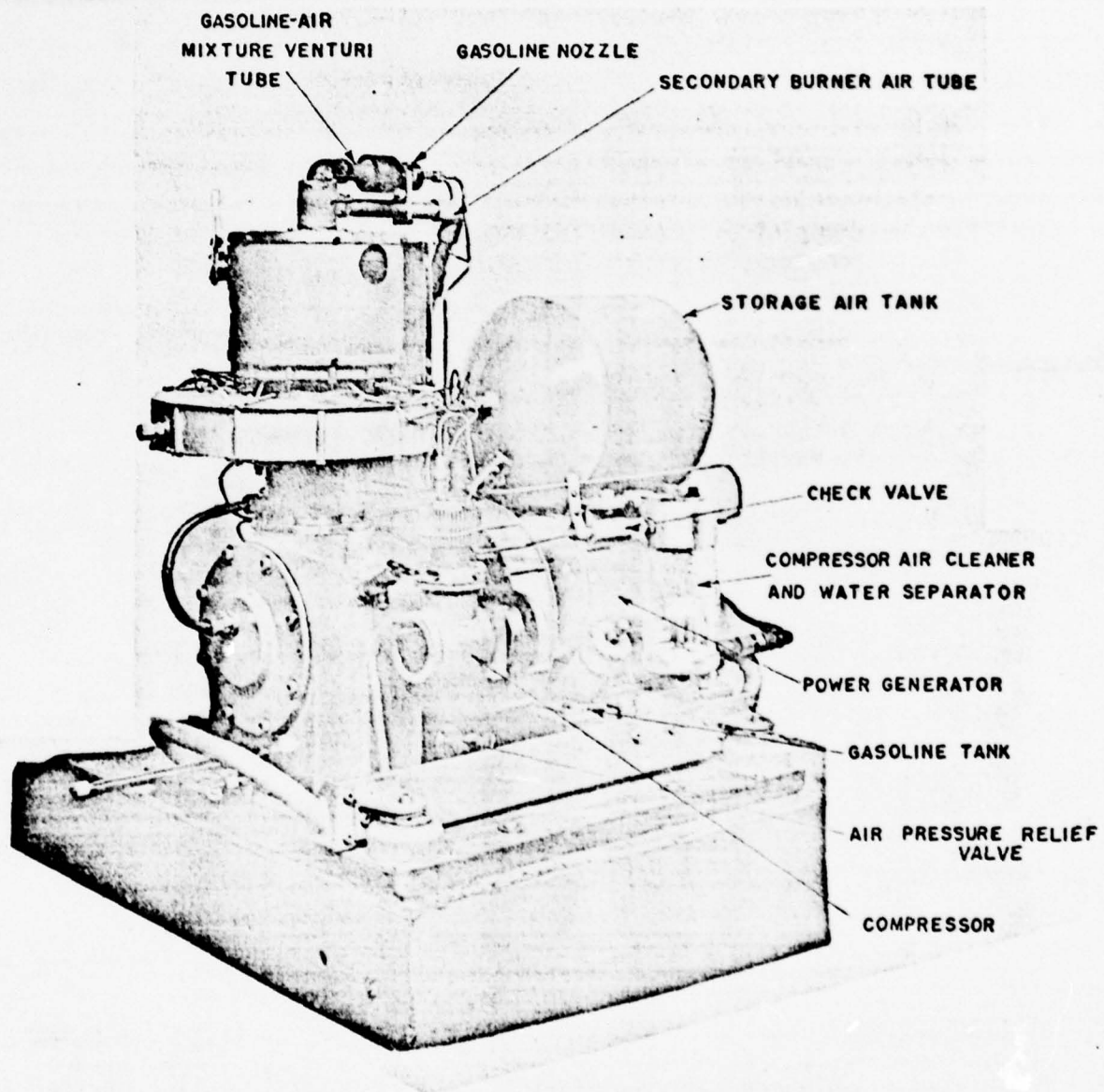
(e) Design modifications be incorporated to simplify the addition of lubricating oil to the crankcase. Removal of the crankcase end cover plate is presently required for this purpose.

(f) A permanently attached, manually operated air pump be provided for pressurizing the air tank of the unit.

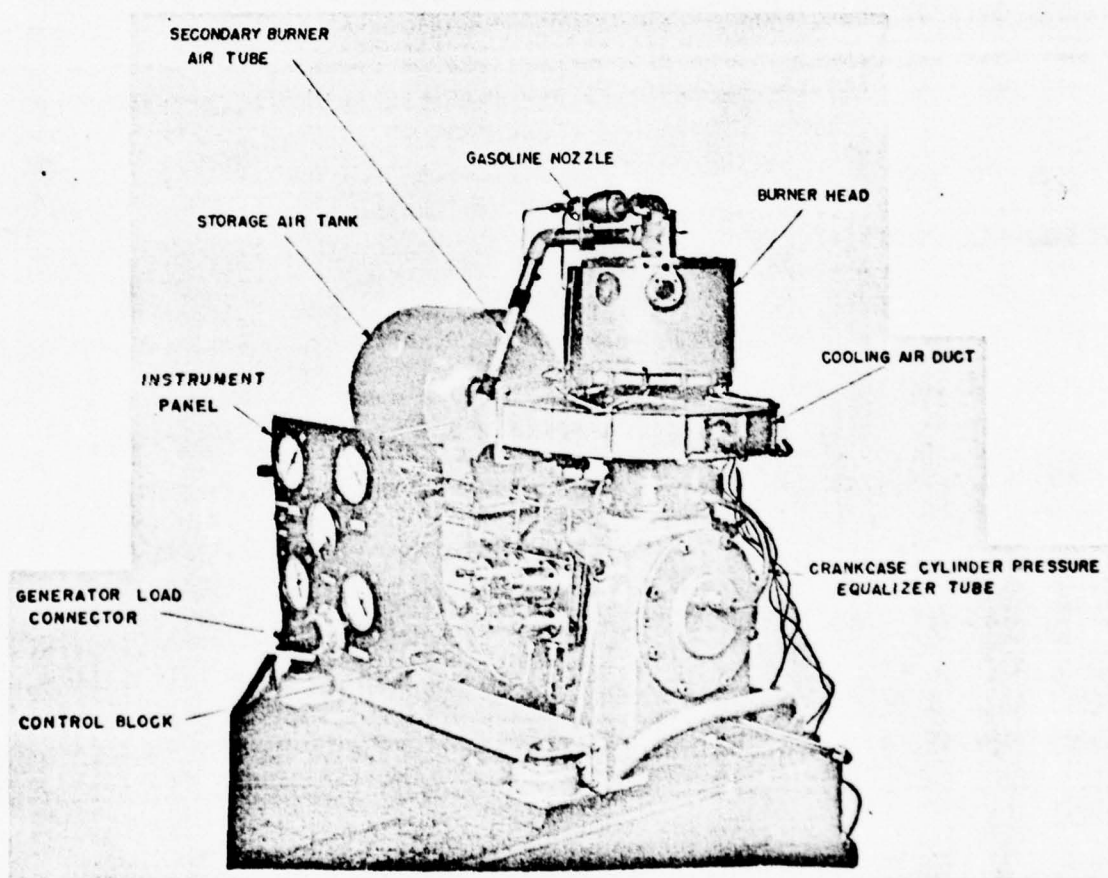
(g) A copper gasket be used to seal the joint between the cylinder and head of the compressor, in lieu of the present lead wire.

(h) The tappet face of the compressor piston be made of a suitable hardened material to withstand wear and resist indentation.

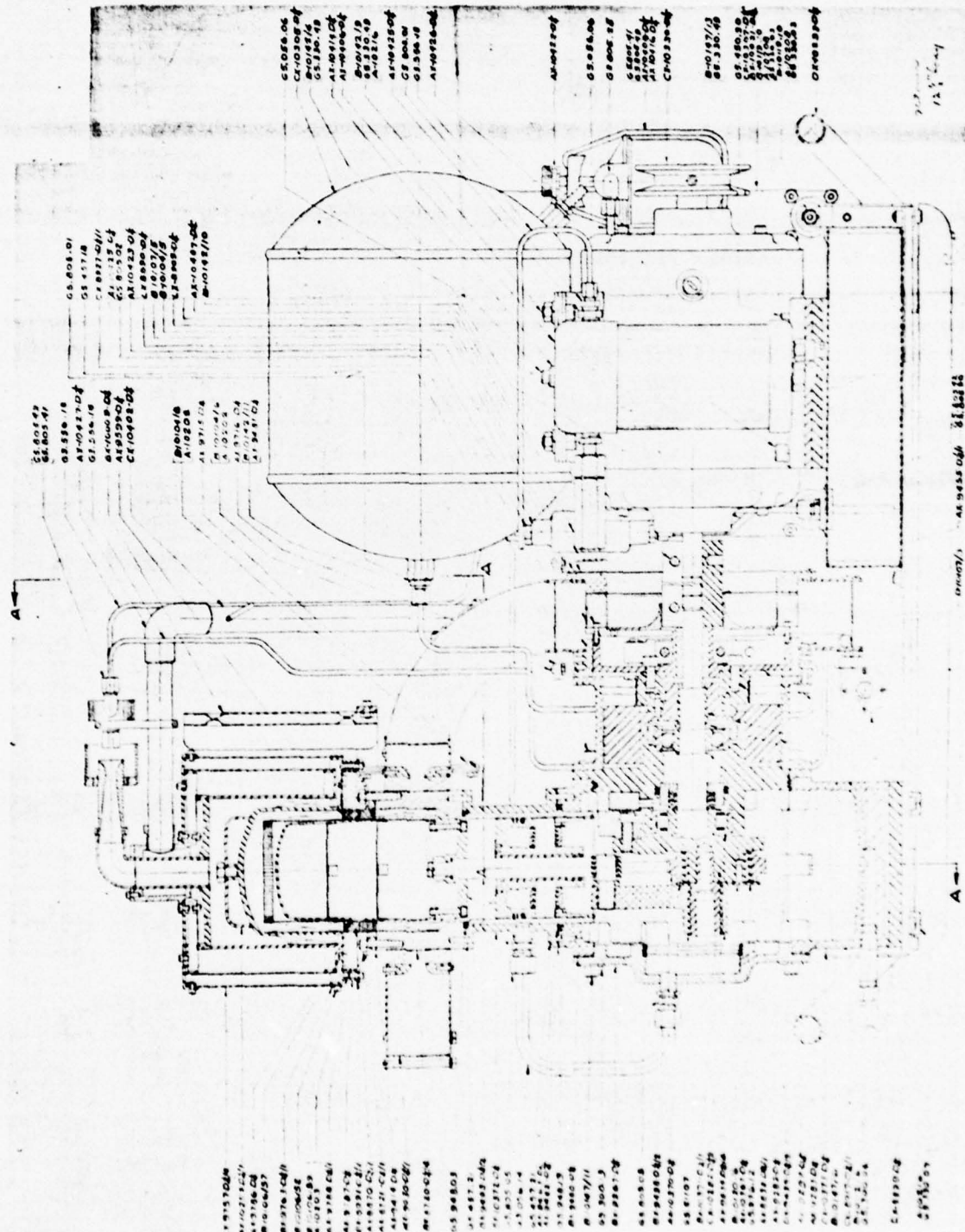
PHILIPS MODEL 1/4D ENGINE
COMPRESSOR SIDE



PHILIPS MODEL 1/4D ENGINE
OPERATING SIDE



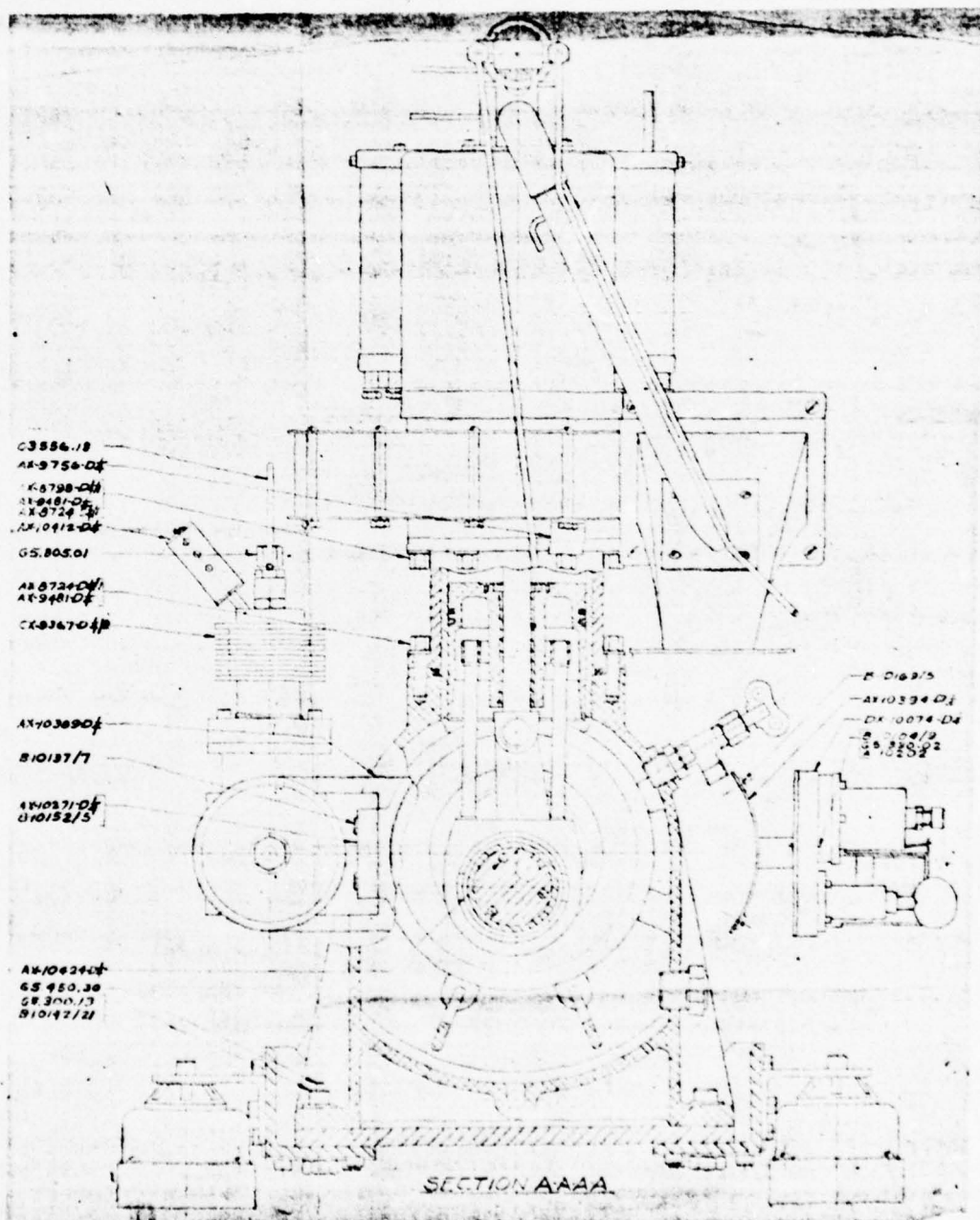
SECTIONAL DRAWING OF ENGINE



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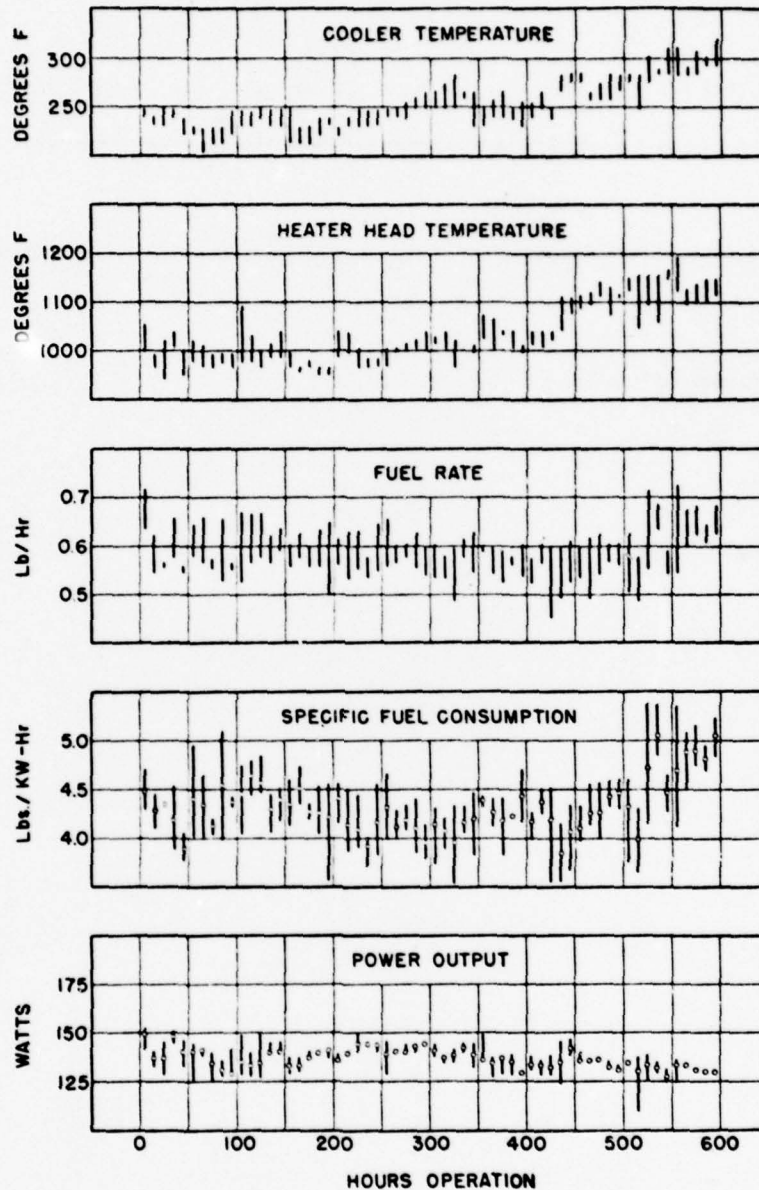
SECTIONAL DRAWING OF ENGINE



MODIFICATIONS MADE IN THIRD PHILIPS MODEL 1/4D ENGINE
(AS COMPARED WITH SECOND ENGINE TESTED AT EES)

1. Gasoline burner fuel flow controlled by manually operated needle valve; burner operated at constant heat. In the original engines, a thermostatically controlled pilot valve alternately switched the burner between the high and low heat conditions.
2. Compressor had a new type head. Suction valve was a silicone rubber steel-backed disc held closed by a cantilever spring. Discharge valve was a flat aluminum disc seating on a flat silicone rubber washer. In the original design, there was a floating flat disc suction valve and a guided conical seat discharge valve.
3. The compressor was equipped with a cotton waste packed air suction cleaner. No air cleaner was provided in the earlier engines.
4. A large water separator-filter was installed in the discharge line of the compressor. A check valve permitted accumulations of water in the transparent filter case to be blown out without loss of air pressure or effect on engine operation. Neither of these features was included in the earlier engines.
5. The crankcase was made of Meehanite cast iron instead of magnesium alloy.
6. The gasoline burner used high pressure air only to atomize the fuel. Secondary air for combustion was supplied from the air duct used to direct air from the flywheel fan to the cooler. In the original design, all of the combustion air was supplied by means of high pressure air jets and aspirators.
7. A gasoline filter was provided in the gasoline suction line.
8. A solenoid valve operated by the electric generator output voltage was provided in the burner air supply line. This valve acted as a safety control to shut off the fuel supply in the event the engine stopped for any reason.
9. A relatively heavy flywheel was provided on the compressor shaft to minimize torque variations. The compressor was driven by a flat belt. The compressors of the original units were chain driven.
10. Set screws were used to retain the piston pins in the pistons and the aluminum plugs in the ends of the piston pins were omitted. In the original design the piston pins were pressed into the piston.

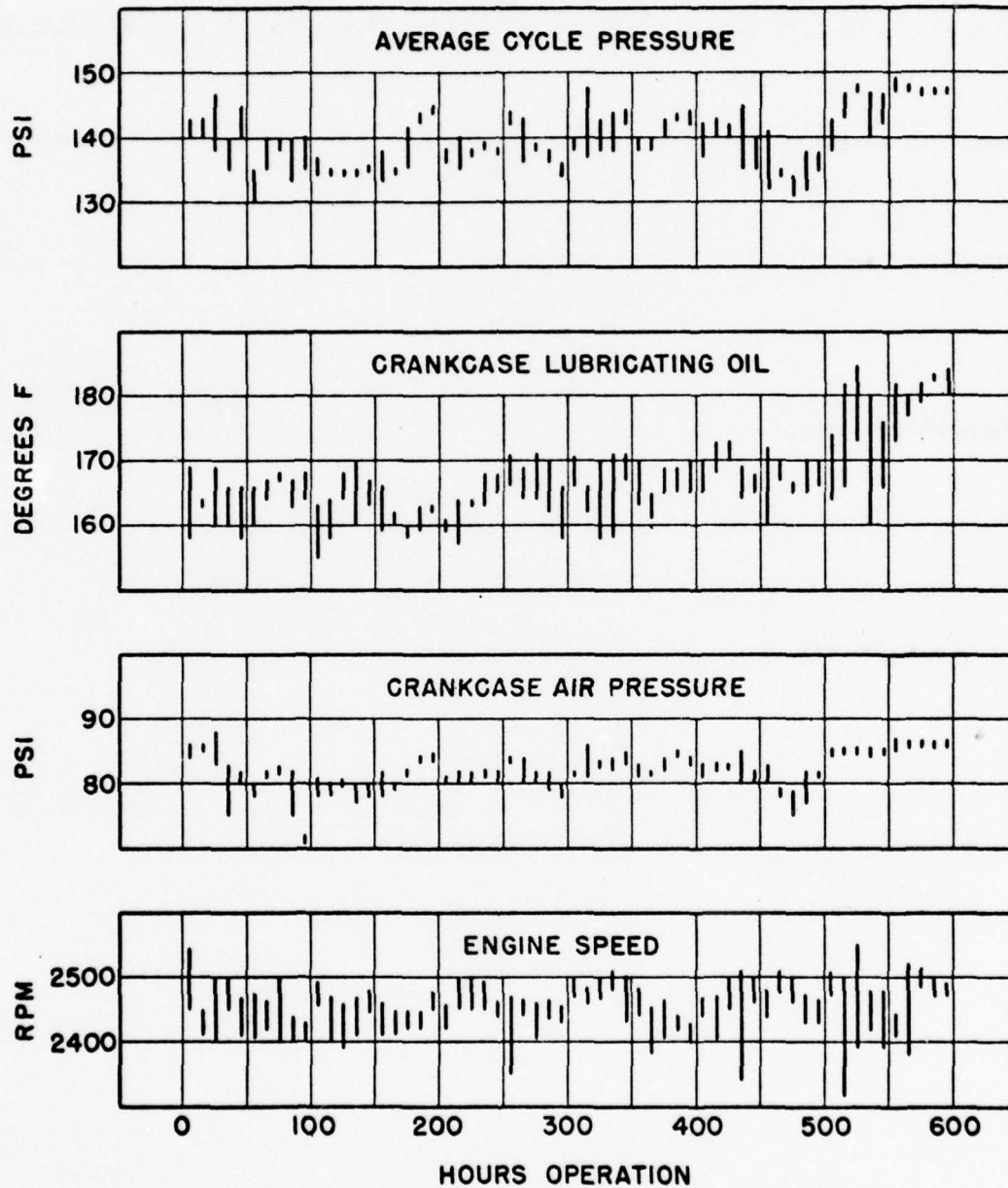
ENDURANCE TEST PERFORMANCE
PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE



- Note: 1. Data points indicate average observed readings for each 10-hour period. Each graph bar indicates the maximum and minimum values for each 10-hour period.
2. All engine operation was with water-white lead-free gasoline except 500 to 530-hour periods during which 80 octane motor gasoline was used.
3. Heater head thermocouple failed by breakage at 329 engine hours. Thermocouple in different location used during balance of test.



ENDURANCE TEST PERFORMANCE
PHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE



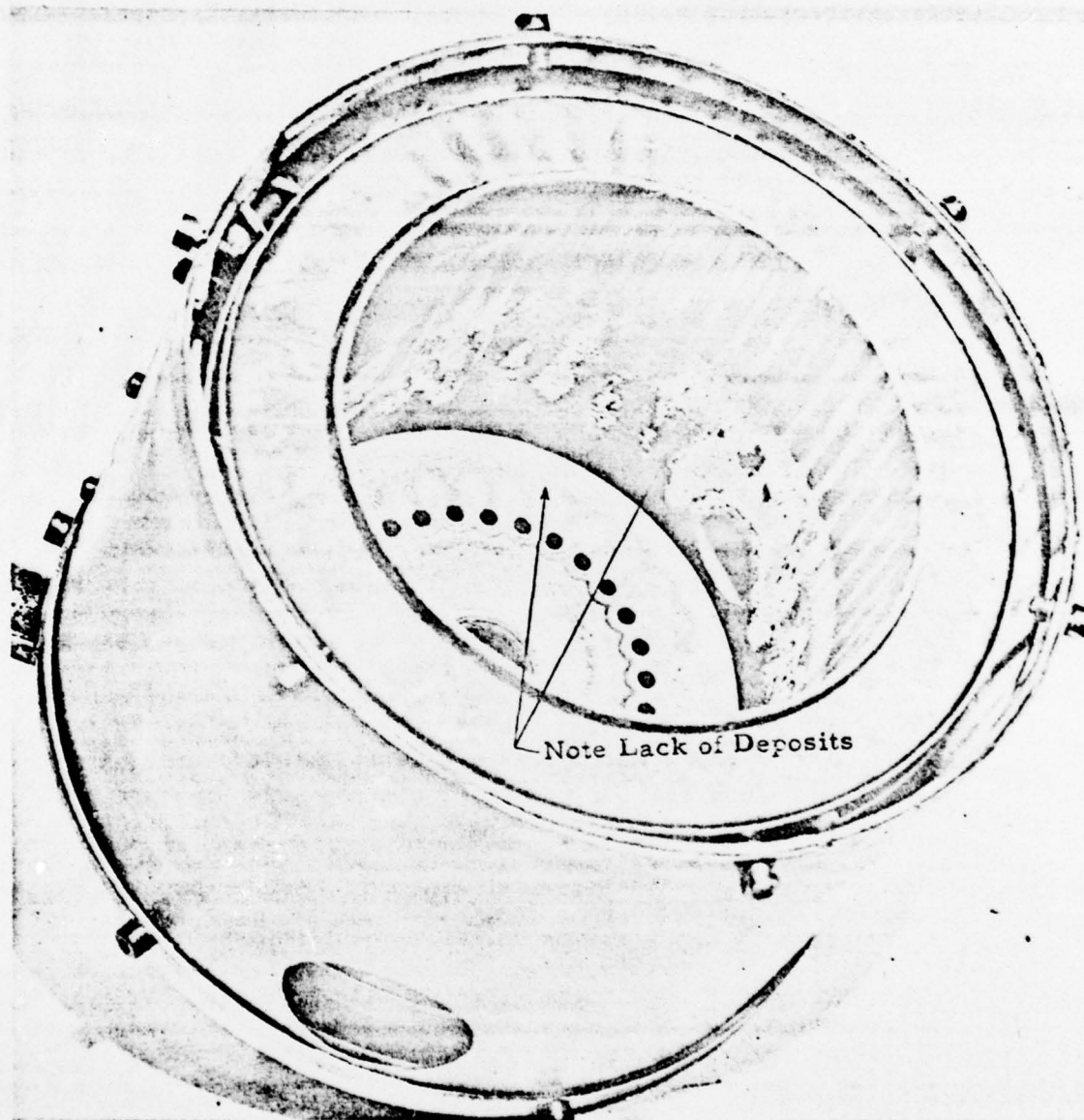
LOG OF OPERATIONPHILIPS MODEL 1/4D EXTERNAL COMBUSTION ENGINE

<u>Engine</u> <u>Operating Hrs.</u>	
29.5	Secured due to accidental closing of fuel float bowl valve.
50	Secured to change crankcase lubricating oil.
100.5	Secured to change crankcase lubricating oil.
100.8	Secured to clean fouled fuel nozzle.
150.5	Secured for demonstration purposes.
151	Secured to change crankcase lubricating oil.
200	Secured to change crankcase lubricating oil.
209.5	Secured for week-end. On attempting to restart, shut-off valve diaphragm was found perforated and stuck to seat. Replaced diaphragm.
250	Secured to change crankcase lubricating oil. On attempting to restart, burner did not operate properly due to heavy carbon deposits in gasoline-air mixture venturi, Plate 11. Cleaned fuel nozzle and venturi tube.
300	Secured to change crankcase lubricating oil.
311	Secured for week-end.
329	Heater head thermocouple failed by breakage of wire. Connected a spare thermocouple.
350	Secured to change crankcase lubricating oil.
400	Secured to change crankcase lubricating oil.
428.5	Secured for week-end.
430	Secured due to failure of compressor to deliver air. Compressor suction valve failed, Plate 12. Installed new compressor head assembly.
431-435	Secured due to difficulty in maintaining adequate heater head temperature. Intermittent operation. Cleaned fuel nozzle and venturi tube.
453.5	Secured to change crankcase lubricating oil.
500	Secured for end of scheduled 500 hour run. Changed crankcase lubricating oil. Changed from Amoco water-white gasoline to 80 octane motor fuel.
500.8	Secured due to difficulty in maintaining 125 watt output with 1110°F heater head temperature. Increased burner air and crankcase pressures.

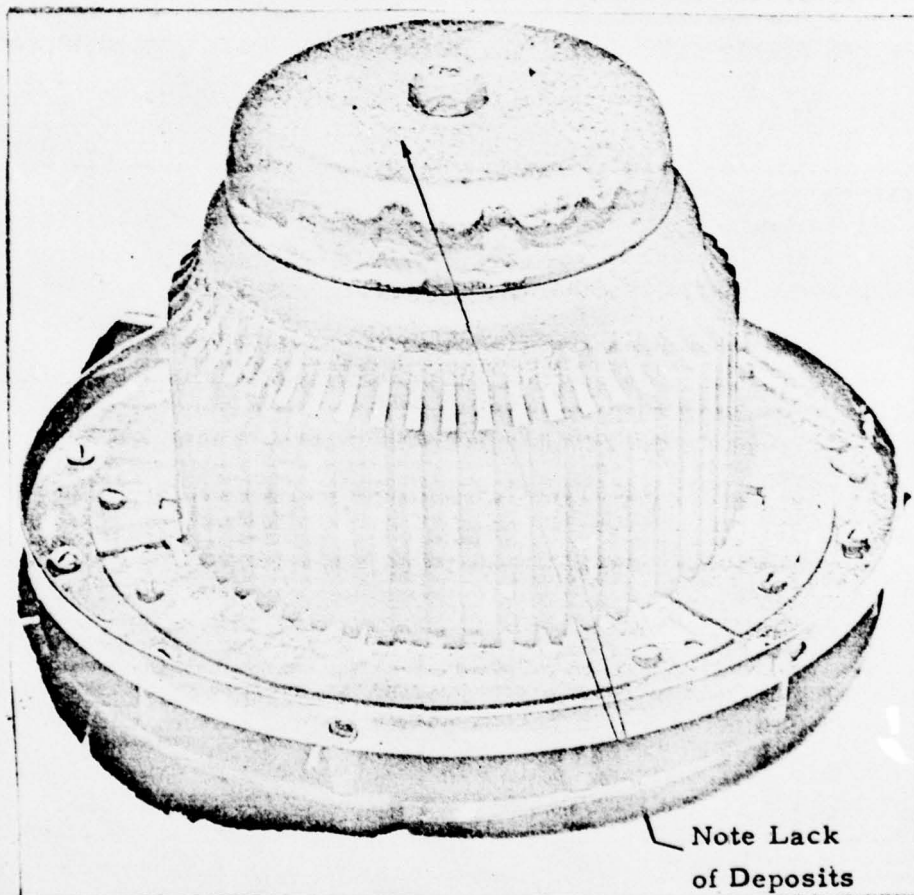
Engine Operating Hrs.	
512	Secured to tighten loose compressor mounting.
514	Secured due to failure of engine to maintain 125 watt output. Cleaned fuel nozzle.
527	Secured. End of 24-hour run with 80 octane motor fuel.
527-530	Intermittent operation of engine for demonstration purposes with 80 octane motor fuel. Fuel nozzle cleaned.
542	Secured for week-end.
550	Secured to change crankcase lubricating oil.
597	Secured due to development of noise and vibration in engine. Crankshaft main roller bearing failed, Plate 13.

- Notes:
- 1 Fuel needle valve adjustments. During the 597 hours of test, adjustments to the fuel needle valve were made on 24 occasions. Operating periods between adjustments ranged from one to 94 hours (average, 23 hours).
 - 2 Compressor lubricating oil additions. A total of 31 additions of lubricating oil were made to the compressor. Operating intervals between additions ranged from 5 to 66 hours (average, 18 hours). In each instance the amount added was less than a teaspoonful.

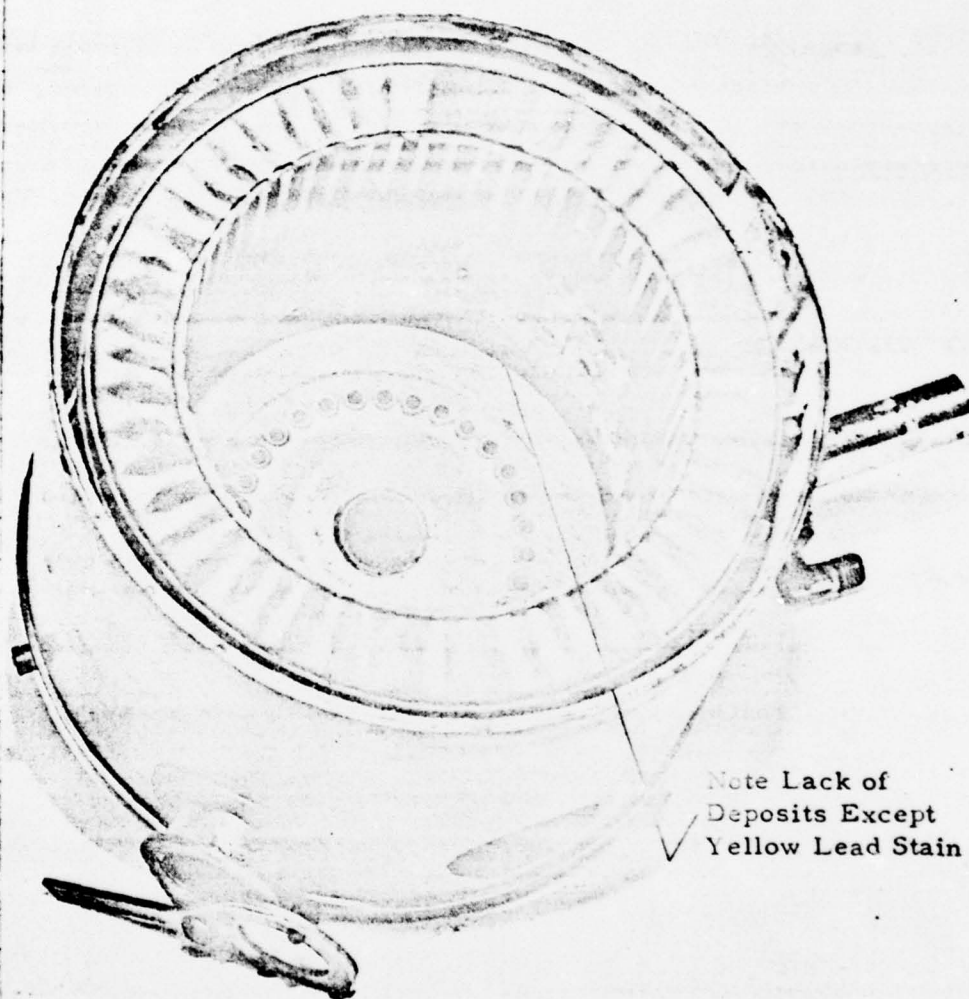
PHILIPS MODEL 1/4D ENGINE BURNER HEAD
FOLLOWING 500 HOURS OPERATION ON UNLEADED GASOLINE



PHILIPS MODEL 1/4D ENGINE
HEATER HEAD
FOLLOWING 500 HOURS OPERATION ON UNLEADED GASOLINE



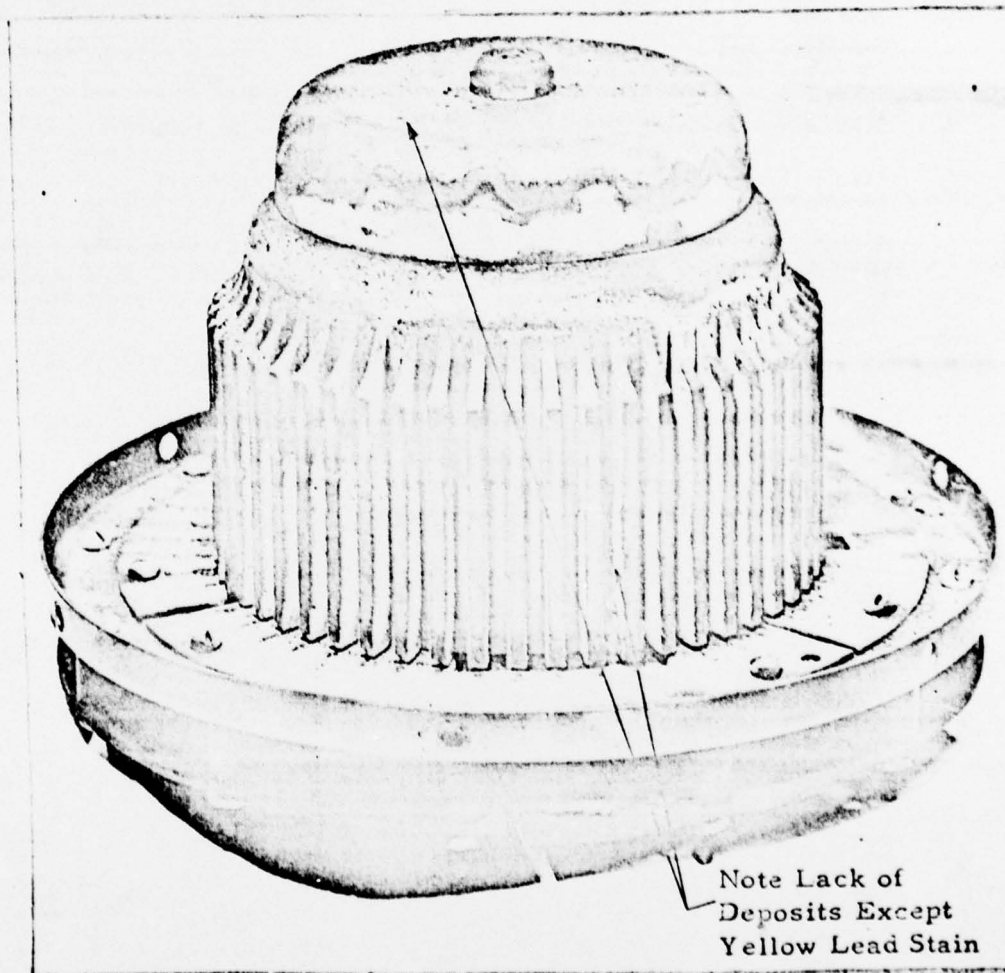
PHILIPS MODEL 1/4D ENGINE BURNER HEAD
FOLLOWING 30 HOURS OPERATION ON 80 OCTANE GASOLINE
AND 500 HOURS OPERATION ON UNLEADED GASOLINE



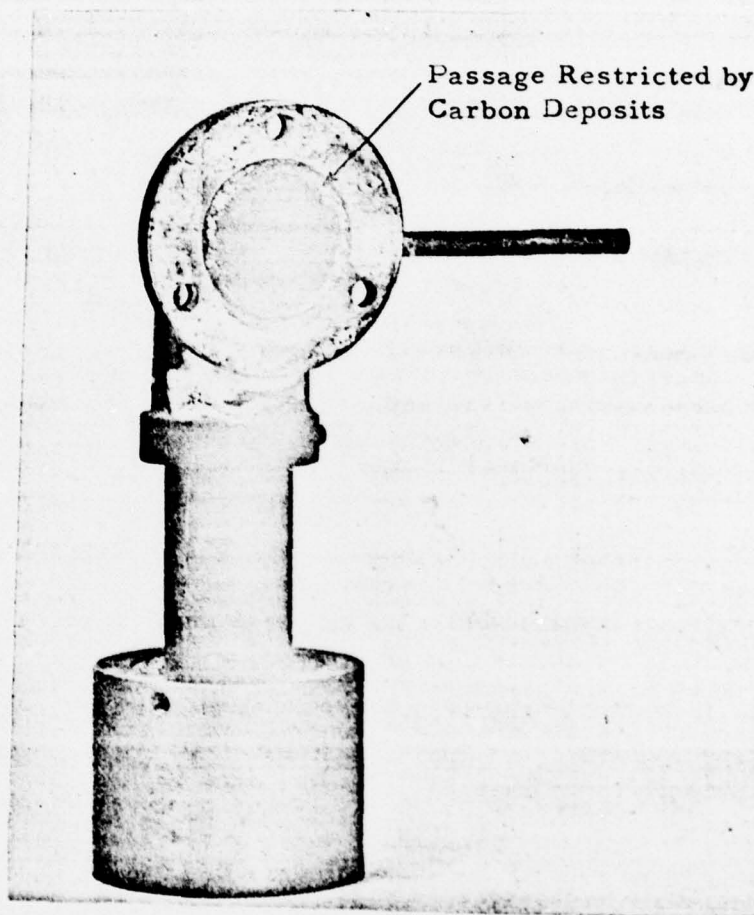
Note Lack of
Deposits Except
✓ Yellow Lead Stain



PHILIPS MODEL 1/4D ENGINE HEATER HEAD
FOLLOWING 30 HOURS OPERATION ON 80 OCTANE GASOLINE
AND 500 HOURS OPERATION ON UNLEADED GASOLINE



PHILIPS MODEL 1/4D ENGINE
GASOLINE-AIR MIXTURE VENTURI TUBE
250 HOURS OPERATION



E.E.S. REPORT C-3599-A(2)

PHILIPS MODEL 1/4D ENGINE
COMPRESSOR SUCTION VALVE
430 HOURS OPERATION

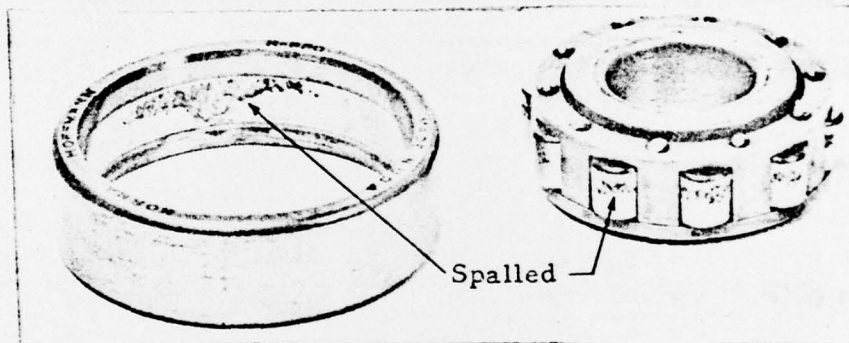


Synthetic Rubber
Composition Seat
Disk Failed



PLATE 12

PHILIPS MODEL 1/4D ENGINE
MAIN ROLLER BEARING
597 HOURS OPERATION



ANALYSES OF GASOLINES

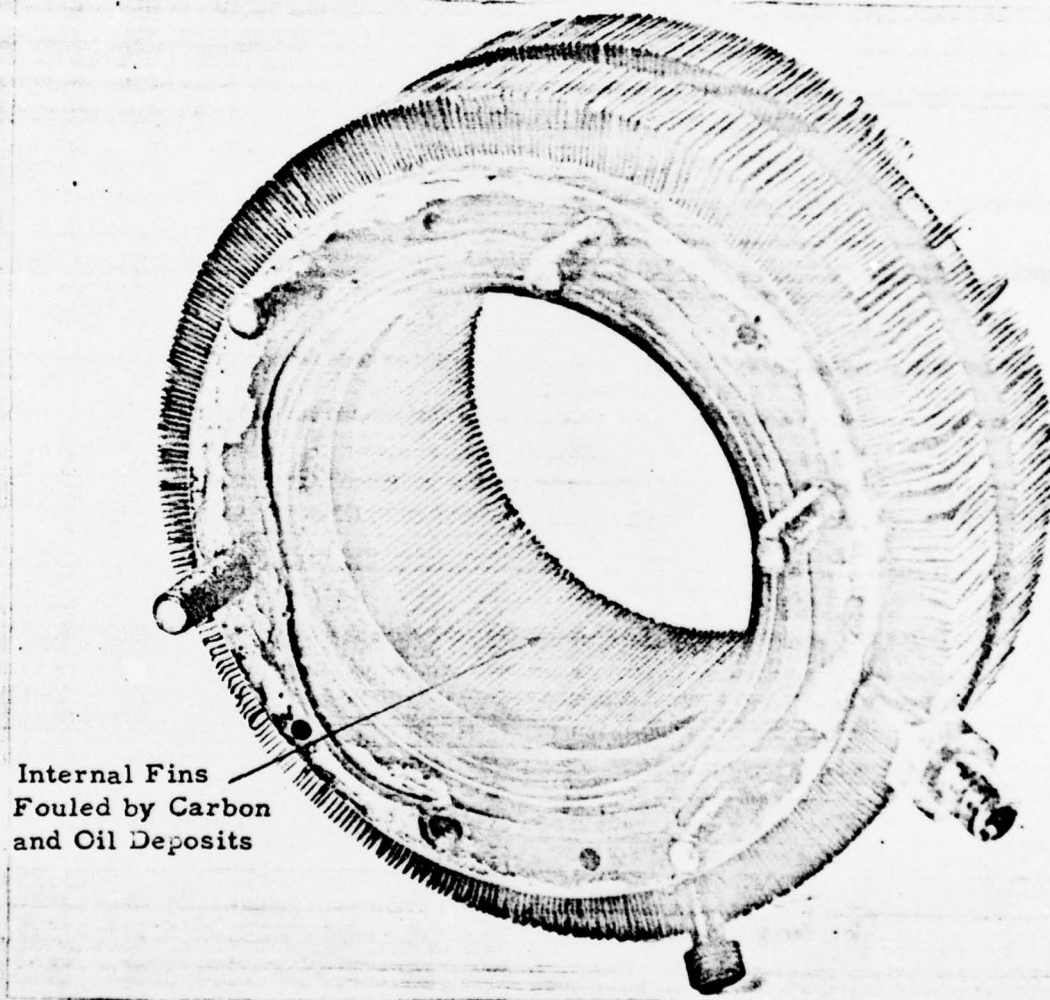
	Amoco Water White Gasoline	80 Octane Motor Fuel
Gum (air jet method) mgs/100 mls	3.4	73.5
Sulfur, pct.	0.09	0.09
Vapor pressure, Reid, psi	6.4	8.9
Specific gravity at 60/60 deg. F.	0.761	0.727
A.P.I. degrees	54.44	63.14
Water tolerance, mls	pass	pass
Heat of combustion, gross value, Btu/lb	19560	20220
Heat of combustion, net value, Btu/lb	18390	18860
Lead content, T.E.L., mls/U.S. gal.	none	0.88
Aromatic content, pct. by vol.	27.4	14.0
Olefins, pct. by vol.	21.6	31.0
Bromine number	39.2	56.5
Distillation range		
Temp. at which 10 pct. evaporated, deg.F.	138	127
Temp. at which 50 pct. evaporated, deg.F.	235	199
Temp. at which 90 pct. evaporated, deg.F.	344	312
End point, deg.F.	395	383
Residue, pct.	0.8	1.2
Evaporation loss, pct.	1.2	0.8
Distillation, uncorrected		
Initial boiling point, deg.F.	107	98
5 cc, deg. F.	134	119
10 cc, deg.F.	149	129
15 cc, deg.F.	159	137
20 cc, deg.F.	171	145
30 cc, deg.F.	193	163
40 cc, deg.F.	215	179
50 cc, deg.F.	238	201
60 cc, deg.F.	260	224
70 cc, deg.F.	288	249
80 cc, deg.F.	317	276
90 cc, deg.F.	348	315
95 cc, deg.F.	370	354
Recovery, pct.	98.0	98.0

ANALYSES OF CRANKCASE LUBRICATING OIL

Albis No. 29 Lubricating Oil

Hours operation of engine	-	100	200	300	500
Hours operation of oil	0	50	50	50	46
Specific gravity, 60/60	0.877	-	-	-	-
A.P.I. degrees, 60/60	29.8	-	-	-	-
Flash point, open cup, deg.F.	425	-	-	-	-
Pour point, deg. F.	+15	-	-	-	-
Viscosity, seconds, SUV					
100 deg. F.	222	204	203	200	225
130 deg. F.	113	-	-	-	-
210 deg. F.	47.6	-	-	-	-
Viscosity index	96.5	-	-	-	-
Color, NPA	3.0	-	-	-	-
Reaction	Neut.	Neut.	Neut.	Neut.	Acid
Neutralization number	0.02	0.14	0.14	0.18	0.30
Precipitation number	None	Trace	None	Trace	None
Carbon residue (ash free),pct.	0.04	-	-	-	-
Ash, pct.	-	-	0.0034	0.004	0.044

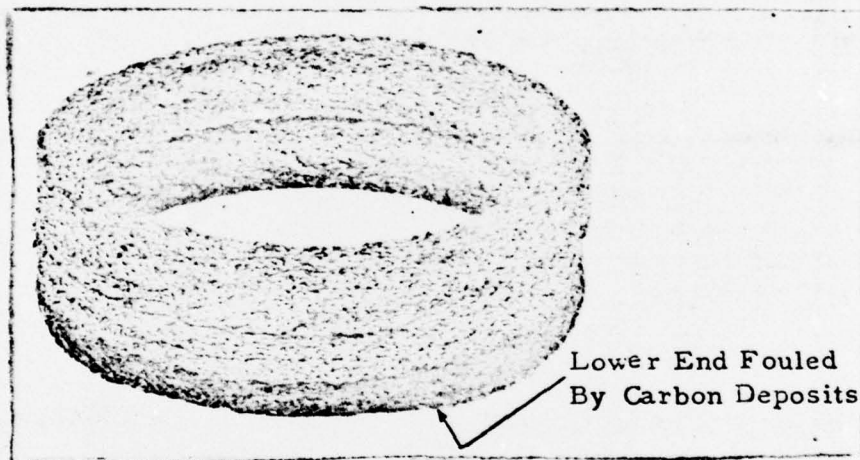
PHILIPS MODEL 1/4D ENGINE
COOLER BLOCK
597 HOURS OPERATION



Internal Fins
Fouled by Carbon
and Oil Deposits



PHILIPS MODEL 1/4D ENGINE
REGENERATOR
597 HOURS OPERATION



PHILIPS MODEL 1/4D ENGINE
COMPRESSOR PISTON
597 HOURS OPERATION

Tappet Surface
Pitted and
Indented



U. S. NAVAL ENGINEERING EXPERIMENT STATION

Annapolis, Maryland

File No. 1116/15/11-1

10 APR 1950

Serial (1116) (925) Test C-1549-A(2)

From: Director

To: Chief of the Bureau of Ships (Code 362)

Subj: E.E.S. Test Report C-1549-A(2). Endurance Test of Phillips Model 1/4D
External Combustion Engine.

Encl: Eleven (11) copies of test report dated 10 March 1950.

1. Eleven copies of the subject report are forwarded herewith.


W. D. Leggett, Jr.

Postgraduate School, Annapolis, Md.

Office of Chief of Engineers, Engineer Research & Dev. Division,
Room 2047, Building T-7, Gravelly Point, Washington-25, D.C.

BuShips (11)

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